1994. Pages 134-143 in A.A. Seawright and C.T. Eason, eds., Proceedings of the Science Workshop on 1080 (December 12-14, 1993, Christchurch, New Zealand). The Royal Society of New Zealand, Miscellaneous Series 28. 173 pp.

Susceptibility of prairie dogs to Compound 1080 (sodium monofluoroacetate) baits and secondary poisoning effects in European ferrets under laboratory conditions

P. J. SAVARIE
G. H. MATSCHKE
R. M. ENGEMAN
K. A. FAGERSTONE
USDA/APHIS/ADC, Denver Wildlife Research Center
P.O. Box 25266, Bldg. 16, Denver Federal Center, Denver, CO USA 80225-0266

Abstract Efficacy and secondary toxicity of 1080 were evaluated for controlling black-tailed prairie dogs (*Cynomys ludovicianus*). No loss in efficacy was observed when prairie dogs were fed 0.022% and 0.035% 1080 bait concentrations when compared with the previously registered level of 0.11%. Tissue (whole body, muscle, or internal organs) from prairie dogs killed by feeding on 1080 grain baits were offered to European ferrets (*Mustela putorius furo*) for 3 days. A ferret died after feeding on internal organs from prairie dogs that consumed 0.11% bait. Gross toxicological symptoms were observed in five ferrets that fed on internal organs and in one ferret that fed on whole body tissue from the 0.11% treatment and in one ferret that fed on internal organs from the 0.035% treatment; however, all seven affected animals fully recovered. No gross toxicological symptoms were observed in any of the ferrets that consumed tissues from prairie dogs killed with the 0.022% 1080 bait. The 0.022% concentration represents an 80% reduction of 1080 when compared with the previously registered 0.11% concentration.

Keywords Sodium monofluoroacetate; 1080 bait feeding tests; prairie dog; ferret; secondary toxicity

INTRODUCTION

In 1990 the U.S. Environmental Protection Agency (EPA) cancelled all Compound 1080 rodenticide registrations because registrants did not provide the data required to meet the registration standards. Before 1990, 1080 bait concentrations ranging from 0.055% to 0.55% were registered for several rodent species. A commonly employed concentration for black-tailed prairie dogs (*Cynomys ludovicianus*) was 0.11%. These 1080 bait concentrations were suspected to be higher than necessary to be effective, but evaluations of lower concentrations were not conducted. The potential implications of using lower bait concentrations are important because 1080 is a non-specific highly acute toxicant with LD_{50} values of less than 10 mg kg^{-1} for most animals (Atzert 1971; McIlroy 1983a, 1983b, 1984; Hudson *et al.* 1984; McIlroy & Gifford 1992). Compound 1080 is potentially hazardous to non-target wildlife and domestic animals through both primary poisoning (direct ingestion of a toxic bait) and secondary poisoning (consumption of an animal killed by primary poisoning). Theoretically, a reduction of 1080 in a bait would reduce both primary and secondary poisoning hazards.

Preliminary unpublished data from the Denver Wildlife Research Center (DWRC) showed that 100% of black-tailed prairie dogs died after feeding on a 0.022% 1080 bait, with the animals consuming an average of 2.7 LD_{50}s. This study was conducted to further investigate the acute oral toxicity and efficacy of 1080 baits to black-tailed prairie dogs. Acute oral toxicity and secondary poisoning hazard tests using European ferrets (*Mustela putorius furo*) as surrogates for the threatened black-footed ferret (*Mustela nigripes*) were also conducted.

MATERIALS AND METHODS

Animal procurement and maintenance

Black-tailed prairie dogs of either sex were live-trapped at Wind Cave National Park, 8 miles north of Hot Springs, Custer County, South Dakota, USA, and transported to the DWRC. Prairie dogs were caged individually in galvanized wire mesh cages (54 × 54 × 40 cm). All prairie dogs were given oats, pelleted laboratory rat and mice chow (Ralston Purina Co., St. Louis, Missouri, USA) and tap water *ad libitum* and were maintained under laboratory conditions for at least 1 week before testing. Prairie dogs weighed 545–1,624 g at the time of testing. European ferrets of either sex were purchased from Marshall Research Animals, Inc., North Rose, New York, USA. All ferrets were caged individually in stainless steel cages (60 × 32 × 45 cm) and had free access to cat chow (Ralston Purina Co.) and water. Ferrets used in the acute oral toxicity test were about 13 weeks old, weighed 551–1180 g, and were maintained under laboratory conditions for 1 week before testing. Ferrets used in the secondary hazard tests were about 19 weeks old, weighed 729–1736 g, and were maintained in the laboratory 5 to 6 weeks before testing. The acute oral toxicity test was conducted in a metal building equipped with a thermostatically controlled water cooler and exhaust fan. The secondary feeding test of prairie dog tissue to ferrets was conducted in a separate laboratory. Animal room temperatures ranged from about 19° C to 21° C and rooms were maintained on a 12 h light-dark cycle: light, 0600–1800; dark, 1800–0600.

Source of 1080

Technical grade 1080 was purchased from Tull Chemical Co., Oxford, Alabama, USA, and assayed 90.2% active ingredient. The appropriate amount of technical 1080 was calculated to compensate for the less than 100% purity, and all 1080 bait concentrations and doses are expressed in amounts of the active ingredient.

Prairie dog and ferret acute oral toxicity LD_{50} tests

Prairie dogs and ferrets were fasted (removal of food but not water) 16 to 18 h before dosing. Solutions of 1080 were prepared in deionized water and administered at the rate of 0.05 ml 100 g^{-1} of body weight; control animals received an equivalent volume of water. Doses of 0.0, 0.13, 0.20, 0.30, and 0.45 mg kg^{-1} were tested in prairie dogs, with three males and seven females randomly assigned by weight to each dose. Each animal was weighed and intubated with a 7.62 cm, 18-gauge intubation tube. After dosing, each prairie dog was placed in its cage containing its regular ration. Prairie dogs were examined twice daily for 14 days after dosing. The combined sex LD_{50} and LD_{99} were calculated by probit analysis (Finney 1971); LD_{50}s for the separate sexes were calculated by Thompson (1947) & Weil (1952).

Doses of 0.0, 0.59, 0.77, 1.0, 1.15, 1.3, 1.5, 1.69, and 2.2 mg kg^{-1} were tested in ferrets. Weight and sex bias were eliminated by ranking the weight and sex of 90 ferrets and 10 ferrets (five males, five females) were randomly assigned to each dose. The combined sex and separate sex LD_{50}s were calculated by probit analysis (Finney 1971). Ferrets were observed at least four times for signs of toxicity on the day of dosing and daily thereafter for 14 days. Food was offered to ferrets about 6 h after dosing.

Prairie dog 3-day bait acceptance test

This test ensured that prairie dogs would consume the oat bait carrier before exposure to the 1080 oat baits. Each prairie dog received 40 g of bait daily for 3 days, and consumption was measured daily. Animals failing to consume 30 g over a 3-day period were removed from further testing to prevent non-feeders from confounding bioassay results.

Prairie dog Initial Bait Acceptance Bioassay (IBAB) test

Baseline data on bait acceptance and mortality were determined in the IBAB test using the average weight (856 g) of test animals and the estimated LD_{99} from the acute oral toxicity test. The LD_{99} for prairie dogs was estimated at 0.41 mg kg^{-1} (see Results) and the concentration of 1080 in the bait equivalent to one LD_{99} on 1 gram of bait for a 1 kg animal was estimated to be 0.035%.

Ten prairie dogs (five males, five females) that passed the 3-day bait acceptance test were randomly selected and weighed. Each animal was fasted for about 16 h before receiving 40 g of the 0.035% 1080 oat bait formulated with 0.9% Alcolec-S®, an adhesive (American Lecithin Co., Atlanta, Georgia, USA). About 24 h later the 1080 bait consumption was recorded. Survivors were given their regular ration and thereafter examined twice daily for 14 days.

Prairie dog Concentration Effect Bioassay (CEB) bait tests

In a series of eight no-choice feeding tests, various concentrations of 1080 oat baits formulated with 1.1% Alcolec-S® were fed in restricted quantities (2.5 g) or *ad libitum* (40 g) for 24 h to prairie dogs previously fasted for 16 h. The bait consumption was recorded and survivors were given their regular ration and checked twice daily for 14 days.

The CEB experimental treatments are summarized in Table 1. In Tests 1 through 6, prairie dogs were randomly selected for each test from those prairie dogs previously tested and passing the 3-day bait acceptance test. In Tests 7 and 8 the prairie dogs were not pretested in the 3-day bait acceptance test. Except for Test 7 which had six males and four females, the other seven tests had equal sex ratios.

The formerly registered prairie dog 1080 bait formulation (0.11%) was used in Test 1. The concentrations of 1080 in Tests 2 through 8 were 82% to 92% lower than 0.11%.

Baiting of prairie dogs with 1080 to obtain tissue for secondary feeding tests with ferrets

Four groups of 36 prairie dogs each, without regard to weight or sex, were randomly assigned to 0.11%, 0.035%, 0.022%, or 0% (control) 1080 bait tests. The 1080 was formulated on oats with 1.2% Alcolec-S®. The control oat bait was also formulated with 1.2% Alcolec-S®. About 24 h before the treated oat baits were offered, untreated oats were removed but laboratory chow, alfalfa cubes, and water remained as food sources. Each animal was then offered 10 g of either 1080 treated or control bait which was removed 24 h later and consumption recorded. Animals were observed for signs of toxicity about 8 h after the bait was offered and at least once daily for 14 days after treatment. Time to death was recorded in hours from 0800 on the day bait was offered. The weight of prairie dogs when found dead was recorded. The mg of 1080 consumed, and mg 1080 consumed kg^{-1} were calculated. Control prairie dogs were euthanized with CO_2 gas after 24 h exposure to bait. Twelve prairie dogs from each of the four groups were randomly assigned as the source of whole body tissue, and the remaining 24 from each group were the source of muscle and internal organ tissues. All carcasses were skinned and the head, feet, and tail removed. For each of the four test groups of prairie dogs, the respective body parts were pooled and ground with an electric meat grinder to obtain three batches of tissues: (1) whole body (bones, muscle, and internal organs); (2) muscle (including bone); and (3) internal organs. The 12 batches of prairie dog tissue were frozen for 35–52 days.

Table 1 Concentration Effect Bioassay experimental treatments to determine efficacy based on 1080 concentrations, availability of bait, and previous exposure to untreated oat bait.

Test no.	% 1080	Bait offered (g)	3-day bait acceptance
1	0.11	40	Yes
2	0.009	2.5	Yes
3	0.018	2.5	Yes
4	0.01	40	Yes
5	0.02	40	Yes
6	0.02	40	Yes
7	0.02	40	No
8	0.02	40	No

Secondary feeding tests of prairie dog tissues to ferrets

To eliminate weight and sex bias, 120 ferrets were ranked by weight and sex and 10 ferrets (five males, five females) were randomly assigned to each of the 12 tissue test groups. Each ferret was prebaited for 1–3 days with 139–142 g of thawed untreated prairie dog tissue. After prebaiting, each ferret was offered 139–142 g of thawed treated or control prairie dog tissue daily for 3 consecutive days. Cat chow was provided during the 14-day posttreatment observation period. Tissue consumed was recorded daily and unconsumed tissue was discarded. Water, but no other food, was available when the ferrets were offered prairie dog tissue. Body weights of ferrets were recorded on the day of prebaiting (test day 0), and on days 1, 7, and 14 posttreatment.

Method of 1080 analysis

Samples for 1080 analysis were prepared according to the method of Okuno *et al.* (1982). The technical 1080, oat baits, and prairie dog tissues were analyzed using a Tracor 560 gas chromatograph equipped with an Ultrabond (1.8 m) packed column. Ferret muscle samples were analyzed using a Hewlett-Packard 5880A gas chromatograph equipped with a SPB–5 (100 m) capillary column. Duplicate analyses were conducted on five 10 g samples for each of the 1080 bait concentrations and one analysis was done per each of five 10 g samples from the control bait. Five 1 g samples from each of the 12 prairie dog tissues (nine treated, three untreated) fed to ferrets were analyzed once only for 1080 as were 1 g samples of ferret muscle. The limit of detection was 0.01 ppm.

Statistics

Except for the LD_{50} values with 95% confidence intervals, results are presented as means ± s.e. One-way and two-way analyses of variance (ANOVA) were used to test for differences among means

(Winer 1971) for prairie dogs offered 0% (control), 0.022%, 0.035%, and 0.11% 1080 baits, and 1080 residues in the treated prairie dog tissues. Duncan's multiple range test at an experiment-wise error rate of .05 was applied to locate specific differences among effects found significant in the ANOVAs.

RESULTS

Prairie dog and ferret acute oral LD_{50} tests

The prairie dog LD_{50} for combined sexes was 0.17 (0.14–0.22) mg kg^{-1}. The LD_{50} for male and female prairie dogs was 0.16 (0.09–0.29) and 0.18 (0.12–0.25) mg kg^{-1}, respectively. Mortalities were recorded 1 to 6 days after dosing. The prairie dog LD_{99} for combined sexes was estimated at 0.41 (0.25–0.65) mg kg^{-1}.

The ferret LD_{50} for combined sexes was estimated to be 1.23 (1.16–1.31) mg kg^{-1}. The LD_{50} for males was 1.26 (1.13–1.42) mg kg^{-1} and 1.19 (1.06–1.34) mg kg^{-1} for females. Symptoms of toxicity such as ataxia, retching, lethargy, vocalizations, musk release, and tremors developed in lethally dosed animals 30 to 40 min after dosing. All deaths occurred within 7 h. Ferrets that survived displayed symptoms of poisoning which included ataxia, thrashing, pedaling, writhing, vocalization, musk release, labored breathing, and development of coma. Survivors appeared normal 24 to 48 h after dosing.

Prairie dog Initial Bait Acceptance Bioassay (IBAB) test

All prairie dogs died after consuming 9.1 ± 1.9 g of 0.035% bait (Table 2). The mean consumption of 1080 was 3.7 ± 0.7 mg kg^{-1} or about 9 LD_{99}s. Three prairie dogs died on day 1, five on day 2, and two on day 3.

Prairie dog Concentration Effect Bioassay (CEB) bait tests

Bait consumed, 1080 consumed, and mortality for the CEB bait tests are summarized in Table 2. There was 100% mortality in all the CEB tests, except for CEB Test 2 in which a restricted quantity (2.5 g) of 0.009% 1080 bait was offered and only 60% mortality was achieved. In the tests where 100% mortality was recorded, the mean consumption of 1080 ranged from 0.46 mg kg^{-1} in CEB Test 3 to 12.0 mg kg^{-1} in CEB Test 1, and these respective values are about one and 29 times the estimated LD_{99} of 0.41 mg kg^{-1}. In two comparative tests with the 0.02% 1080 bait, the prebaited prairie dogs (CEB Test 6) consumed no more 1080 bait than prairie dogs not prebaited (CEB Test 7).

Feeding prairie dogs with 1080 bait to obtain tissue for secondary feeding tests with ferrets

Analysis of 1080 in the three prepared baits indicated very close agreement with the nominal 1080 concentrations. The nominal % concentrations (with mean assays ± s.e., n = 10) were: 0.11 (0.11 ± 0.00), 0.035 (0.034 ± 0.001), and 0.022 (0.022 ± 0.001). No 1080 was detected in the control bait.

Bait consumption and time of death are presented for each of the four groups of prairie dogs offered either 0.11%, 0.035%, 0.022% 1080 treated

Table 2 Summary of efficacy results from prairie dog Initial Bait Acceptance Bioassay (IBAB) and Concentration Effect Bioassay (CEB) tests. [a] Values are means ± s.e., n = 10 except as noted. [b] n = 9

Test	% 1080	Bait offered (g)	Bait consumed (g)	1080 consumed (mg kg^{-1})	LD_{99} consumed	Mortality	Time to death (h)
IBAB	0.035	40	9.1 ± 1.9[a]	3.7 ± 0.7	9	10/10	29 ± 6
CEB–1	0.11	40	9.4 ± 1.4	12.0 ± 1.8	29	10/10	17 ± 4
CEB–2	0.009	2.5	2.5 ± 0.0	0.27 ± 0.0	0.6	6/10	39 ± 3
CEB–3	0.018	2.5	2.2 ± 0.2	0.46 ± 0.0	1	10/10	43 ± 12
CEB–4	0.01	40	14.6 ± 1.6	1.4 ± 0.1	3	10/10	23 ± 6
CEB–5	0.02	40	16.4 ± 1.8	3.3 ± 0.4	8	10/10	23 ± 6
CEB–6	0.02	40	13.4 ± 1.7	2.8 ± 0.4	7	10/10	24 ± 7
CEB–7	0.02	40	12.1 ± 1.2[b]	2.2 ± 0.2[b]	5	10/10	24 ± 8
CEB–8	0.02	40	8.3 ± 1.4	1.7 ± 0.3	4	10/10	20 ± 5

or untreated baits (Table 3). No prairie dogs died that were offered control bait. All prairie dogs (n=108) died after being offered treated bait. The mean body weight of male prairie dogs (950 g) was higher ($P < .01$) than the mean body weight of females (830 g). However, there was no difference detected in the mean amount of bait consumed by either sex. The mean amounts of the 0.11% (5.0 g) and 0.035% (6.1 g) 1080 baits consumed were lower ($P < .05$) than the amounts of either control (7.8 g) or 0.022% (7.5 g) 1080 bait consumed. Differences existed among the doses for mg and mg kg^{-1} consumed by prairie dogs ($P < .001$ for both variables). Both the mg (5.6) and the mg kg^{-1} of 1080 consumed (6.5) were higher ($P < .05$) for prairie dogs fed the 0.11% bait than those fed either of the two lower concentrations, which were not statistically different from each other (Table 3).

Analysis of 1080 in prairie dog tissues

Residue analyses showed that 1080 was highest in internal organs, intermediate in whole body, and least in muscle for each of the three concentrations (Table 4). The 1080 residues in each of the three tissues from prairie dogs that consumed the 0.11% bait were higher ($P < .05$) than residues in tissues from prairie dogs that consumed either 0.035% or 0.022% baits. Residues in muscle and internal organs from prairie dogs fed 0.035% 1080 bait were higher ($P < .05$) than residues from prairie dogs fed 0.022% bait; but mean residues in whole body tissue from prairie dogs offered either 0.035% or 0.022% 1080 bait were not statistically different.

Secondary feeding tests of prairie dog tissues to ferrets

Table 5 summarizes ferret consumption of tissue from prairie dogs killed by eating 0.11%, 0.035%, 0.022% 1080 bait, or control bait. These data were not analyzed statistically because ferrets were not offered an *ad libitum* amount of tissue. For some treatments, ferrets ate less tissue on the first day of treatment than during pretreatment, and tissue consumption appeared to be related to both sex and 1080 residue

Table 3 Bait and toxin consumption and time of death for prairie dogs offered 10 g of 1080 bait at concentrations of 0%, 0.022%, 0.035%, and 0.11%. [a]Wt values are means ± s.e.

% 1080 bait	Sex and body weight (g)		n	Bait consumed (g)	1080 consumed (mg)	1080 consumed (mg kg^{-1})	Time to death (h)
0.11	M&F	886 ± 25[a]	36	5.0 ± 0.6	5.6 ± 0.6	6.5 ± 0.8	36 ± 4
	M	940 ± 27	21	5.4 ± 0.8	6.2 ± 0.8	6.8 ± 1.0	28 ± 5
	F	811 ± 38	15	4.3 ± 0.8	4.8 ± 1.0	6.2 ± 1.3	47 ± 7
0.035	M&F	868 ± 32	36	6.1 ± 0.5	2.1 ± 0.2	2.5 ± 0.2	40 ± 4
	M	923 ± 31	21	6.0 ± 0.6	2.1 ± 0.2	2.3 ± 0.3	38 ± 6
	F	830 ± 26	15	6.3 ± 0.8	2.2 ± 0.3	2.6 ± 0.3	42 ± 5
0.022	M&F	928 ± 24	36	7.5 ± 0.4	1.7 ± 0.1	1.8 ± 0.1	32 ± 4
	M	956 ± 23	29	7.7 ± 0.4	1.7 ± 0.1	1.8 ± 0.1	31 ± 5
	F	821 ± 61	7	7.0 ± 0.6	1.6 ± 0.1	1.9 ± 0.1	40 ± 12
0	M&F	926 ± 22	36	7.8 ± 0.4	—	—	—
	M	981 ± 29	20	8.0 ± 0.6	—	—	—
	F	857 ± 26	16	7.4 ± 0.7	—	—	—

Table 4 Residue of 1080 in tissues from prairie dogs killed after consuming 1080 grain baits. [a] Values are means ± s.e., $n = 5$. [b] None detected (limit of detection = 0.01 ppm).

% 1080 bait	Tissue Residue (ppm) Whole body	Muscle	Internal organs
0.11	7.7 ± 0.2[a]	2.3 ± 0.1	13 ± 0.8
0.035	1.1 ± 0.1	0.8 ± 0.0	4.1 ± 0.1
0.022	1.2 ± 0.0	0.6 ± 0.0	2.2 ± 0.0
0	ND[b]	ND	ND

in the tissue. Compared with untreated prebait tissue consumption, tissue consumption by both male and female ferrets was reduced for whole body (7.7 ppm 1080) and internal organs (13 ppm) but only the females showed reduced muscle consumption (2.3 ppm) from the prairie dogs fed 0.11% 1080 bait. From prairie dogs killed by the 0.035% 1080 bait, female ferrets consumed less whole body (1.1 ppm) and muscle (0.8 ppm) tissue than males, and both males and females had reduced consumption of internal organs (4.1 ppm) as compared with the controls. With tissue of prairie dogs killed by the 0.022% bait, females, in general, had reduced food consumption for each of the 3 tissues (whole body, 1.2 ppm; muscle, 0.6 ppm; or internal organs, 2.2 ppm). The mean amount of tissue consumed by female ferrets was always less than that consumed by males for each of the three types of control tissue.

More male than female ferrets displayed clinical signs of sublethal toxicity including lethargy, ataxia, and writhing from eating tissues of 1080-killed prairie dogs (Table 6). Normal behavior returned in 2–3 days. One male ferret died 2 days posttreatment after feeding on internal organs (13 ppm) from prairie dogs that consumed 0.11% 1080 bait. 1080 was detected (<0.03 ppm) in this ferret. No residues

Table 5 Ferret consumption of treated tissue from prairie dogs killed after consuming 1080 baits. [a] Values are means ± s.e., n = 5.

% Bait Tissue (ppm 1080)	Sex	Tissue consumed (g) Untreated	Treated Day 1	Treated Day 2	Treated Day 3	Total 1080 consumed mg kg^{-1}
0.11						
Whole body	F	114 ± 16[a]	61 ± 8	38 ± 6	32 ± 4	1.1 ± 0.13
(7.7)	M	140 ± 0	120 ± 4	51 ± 10	48 ± 9	1.3 ± 0.14
Muscle	F	128 ± 8	105 ± 20	93 ± 19	51 ± 9	0.66 ± 0.10
(2.3)	M	140 ± 0	140 ± 0	140 ± 0	141 ± 0	0.68 ± 0.02
Internal	F	102 ± 11	41 ± 2	24 ± 3	21 ± 2	1.5 ± 0.07
organs (13)	M	138 ± 2	87 ± 4	58 ± 7	34 ± 8	1.7 ± 0.13
0.035						
Whole body	F	114 ± 9	65 ± 19	72 ± 9	58 ± 12	0.24 ± 0.05
(1.1)	M	140 ± 0	140 ± 0	140 ± 0	140 ± 0	0.32 ± 0.02
Muscle	F	100 ± 14	89 ± 7	92 ± 16	53 ± 13	0.22 ± 0.02
(0.8)	M	140 ± 0	140 ± 0	140 ± 0	140 ± 0	0.22 ± 0.02
Internal	F	82 ± 10	75 ± 6	56 ± 3	46 ± 3	0.86 ± 0.05
organs (4.1)	M	140 ± 0	135 ± 3	54 ± 13	70 ± 20	0.72 ± 0.08
0.022						
Whole body	F	90 ± 16	74 ± 7	70 ± 8	69 ± 5	0.28 ± 0.02
(1.2)	M	140 ± 0	126 ± 15	118 ± 22	141 ± 0	0.32 ± 0.04
Muscle	F	103 ± 15	94 ± 20	106 ± 15	76 ± 17	0.14 ± 0.04
(0.6)	M	133 ± 7	125 ± 15	118 ± 22	118 ± 23	0.17 ± 0.03
Internal	F	102 ± 11	71 ± 19	84 ± 9	53 ± 4	0.46 ± 0.05
organs (2.2)	M	125 ± 14	115 ± 25	133 ± 8	138 ± 2	0.62 ± 0.07
0						
Whole body	F	123 ± 11	112 ± 12	85 ± 14	83 ± 13	—
(0)	M	136 ± 3	140 ± 0	140 ± 0	140 ± 0	—
Muscle	F	132 ± 5	115 ± 11	97 ± 20	90 ± 15	—
(0)	M	140 ± 0	140 ± 0	140 ± 0	140 ± 0	—
Internal	F	127 ± 6	81 ± 10	97 ± 7	75 ± 10	—
organs (0)	M	140 ± 0	140 ± 0	138 ± 2	140 ± 0	—

Table 6 Gross behavioral symptoms observed in ferrets that were fed tissues from prairie dogs killed after consuming 1080 baits. [a] 5 male and 5 female ferrets were tested per tissue.

	Concentration of 1080 in bait		
Tissue[a]	0.11%	0.035%	0.022%
Whole body	No mortality 1/5 males intoxicated	No mortality No intoxication	No mortality No intoxication
Muscle	No mortality No intoxication	No mortality No intoxication	No mortality No intoxication
Internal organs	1/5 males died 3/4 males intoxicated 2/5 females intoxicated	No mortality 1/5 males intoxicated	No mortality No intoxication

Table 7 Body weight of ferrets offered treated tissue from prairie dogs killed after consuming 1080 baits. [a] Values are means ± s.e., $n = 5$ except as noted. [b] $n = 4$.

% Bait Tissue (ppm 1080)	Sex	Pretreatment	Weight (g) Posttreatment Day 1	Day 7	Day 14
0.11					
Whole body	F	931 ± 40[a]	895 ± 33	958 ± 30	977 ± 28
(7.7)	M	1,303 ± 71	1,277 ± 62	1,419 ± 67	1,489 ± 62
Muscle	F	864 ± 27	897 ± 28	952 ± 26	957 ± 33
(2.3)	M	1,402 ± 47	1,495 ± 43	1,582 ± 31	1,627 ± 40
Internal organs	F	805 ± 38	737 ± 43	809 ± 45	820 ± 36
(13)	M	1,434 ± 93	1,366 ± 82	1,620 ± 30[b]	1,645 ± 32[b]
0.035					
Whole body	F	896 ± 36	924 ± 46	948 ± 46	975 ± 56
(1.1)	M	1,481 ± 81	1,595 ± 75	1,682 ± 83	1,703 ± 73
Muscle	F	910 ± 21	932 ± 29	963 ± 30	979 ± 31
(0.8)	M	1,389 ± 80	1,491 ± 67	1,500 ± 55	1,551 ± 64
Internal organs	F	886 ± 34	852 ± 29	912 ± 38	925 ± 39
(4.1)	M	1,465 ± 39	1,433 ± 41	1,589 ± 37	1,653 ± 42
0.022					
Whole body	F	927 ± 14	924 ± 22	946 ± 26	940 ± 24
(1.2)	M	1,514 ± 81	1,557 ± 67	1,586 ± 75	1,572 ± 80
Muscle	F	907 ± 53	927 ± 40	924 ± 50	908 ± 60
(0.6)	M	1,385 ± 40	1,436 ± 20	1,460 ± 44	1,439 ± 54
Internal organs	F	988 ± 14	988 ± 18	1,009 ± 23	1,006 ± 33
(2.2)	M	1,443 ± 106	1,504 ± 84	1,589 ± 74	1,591 ± 63
0					
Whole body	F	867 ± 45	920 ± 25	950 ± 19	971 ± 20
(0)	M	1,510 ± 47	1,647 ± 39	1,654 ± 52	1,692 ± 51
Muscle	F	817 ± 12	906 ± 18	930 ± 22	964 ± 25
(0)	M	1,349 ± 64	1,451 ± 64	1,520 ± 71	1,568 ± 78
Internal organs	F	950 ± 44	1,016 ± 31	1,031 ± 38	1,041 ± 48
(0)	M	1,317 ± 65	1,501 ± 57	1,529 ± 73	1,531 ± 91

of 1080 were detected in ferrets that displayed sublethal symptoms and survived. No signs of intoxication were noted in ferrets that fed on the control tissues.

Body weights of ferrets that consumed tissue from prairie dogs killed by eating 0.11%, 0.035%, 0.022% 1080 bait, and control bait are shown in Table 7. A 2–8% loss in mean body weight occurred on posttreatment day 1 for males and females fed whole body (7.7 ppm 1080) and internal organs (13 ppm) from prairie dogs killed with 0.11% 1080 bait. At 7 and 14 days posttreatment, the mean body weight for each treatment was equal to or greater than the pretreatment mean body weight.

DISCUSSION

Results of these prairie dog 1080 bait feeding studies demonstrate that lower concentrations of 1080 (0.022% and 0.035%) are as lethal to prairie dogs as the previously used 0.11% 1080 bait, that far exceeds the amount of 1080 required to produce 100% mortality. The application rate of the 0.11% 1080 bait in the field was 4 g of 1080 bait per prairie dog burrow entrance, and this amount contained 4.4 mg of 1080, or about 11 times the LD_{99} value for a 1-kg prairie dog. In this study, 1080 baits as low as 0.022% produced 100% mortality, but the animals only consumed about four LD_{99}s, with a corresponding reduction in 1080 residues in the prairie dog tissues.

The highest secondary toxicity potential is with the 0.11% bait, is low to moderate with the 0.035% bait, and very low for the 0.022% bait. The internal organs at the 0.11% level present the highest potential hazard. One male ferret died that consumed internal organs from the 0.11% treatment group, and gross symptoms of toxicity were noted in other males and females that consumed internal organs from the 0.11% and 0.035% treated prairie dogs. No symptoms of toxicity were observed in ferrets that consumed tissue from prairie dogs that consumed 0.022% 1080 bait.

The 28-day dietary LC_{50}s for mink (*Mustela vison*) and for European ferrets were reported to be 3.2 and 9.4 ppm, respectively (Hornshaw *et al.* 1986). In the present study, lethal residues of 1080 for a mink or ferret 28-day dietary LC_{50} were in the whole body and internal organ tissues from prairie dogs killed with 0.11% 1080 bait, and in the internal organs from prairie dogs killed with 0.035% 1080 bait (Table 4). Prairie dogs killed with the lowest bait tested, 0.022% 1080, had the highest 1080 residues in the internal organs (2.2 ppm), a level that probably would not cause lethality in a mink or ferret 28-day dietary test. However, in addition to causing mortality, feeding on 1080 diets can cause sublethal symptoms. Dietary exposure of mink to 0.8 ppm 1080 for 2 months before breeding caused severely impaired reproduction, and red and white cell counts were depressed in young ferrets fed 1.08 to 3.5 ppm 1080 diets for 28 days (Hornshaw *et al.* 1986). Studies to evaluate recovery of the effected animals were not conducted. Reversible testes degeneration and altered spermatogenesis have been reported in laboratory rats exposed to 1080 (Sullivan *et al.* 1979). More studies to evaluate recovery from 1080 sublethal toxicity are needed.

Mammalian carnivores are generally recognized as being highly susceptible to 1080 poisoning (Hegdal *et al.* 1981; Colvin *et al.* 1988) but laboratory tests have shown that this is not always the case. No mortality was observed in mink fed eviscerated rabbit carcasses as 40% of their total diet (Aulerich *et al.* 1987). The rabbits were killed by 7 ppm 1080 bait and these investigators noted that the gastrointestinal tract contents were probably the source of toxicity from primary animals. In our study, the highest residues of 1080 were found in the internal organs which included contents of the gastrointestinal tract (Table 4). Marsh *et al.* (1987) observed no mortalities in coyotes (*Canis latrans*) that consumed one or two California ground squirrels (*Spermophilus beecheyi douglasii*) poisoned by ingesting 1 g of 0.05% 1080 bait, but five of six coyotes died after consuming one or two ground squirrels poisoned by ingesting 6 g of 0.05% 1080 bait. In tests designed to evaluate the potential hazard of the Livestock Protection Collar, no mortalities were observed in striped skunks (*Mephitis mephitis*) or golden eagles (*Aguila chrysaetus*) fed diets containing 4.1 and 7.7 ppm 1080, respectively, for 5 days (Burns *et al.* 1991). Three of the six eagles displayed sublethal symptoms (lethargy, loss of muscular strength), but all recovered with no further complications. No secondary poisoning was observed in coyotes, dogs (*Canis familiaris*), striped skunks, or black billed magpies (*Pica pica*) fed tissues of coyotes killed with 1080 baits (Burns *et al.* 1986).

Primary and secondary hazards to wildlife associated with aerial application of 0.075% 1080 bait to control California ground squirrels (*Spermophilus beecheyi*) were evaluated by Hegdal *et al.* (1986). The ground squirrel population was reduced by 85%. Primary hazards were found in other rodent species and desert cottontail rabbits (*Sylvilagus audubonii*). Secondary hazards to mammalian predators (coyotes, bobcats (*Felis rufus*), stripped skunks) were observed. The mean 1080 residue in stomachs of ground squirrels collected 8 h to 5 days after treatment was 23.3 ppm. Secondary hazards to insectivorous birds, probably from eating 1080 killed ants, were recorded. No mortalities were observed while monitoring raptors.

Under the right circumstances, 1080 baiting can be done with minimal hazards to non-target wildlife. In 1986, nearly 50,000 4 mg 1080 single dose baits were used in an effort to extirpate introduced arctic foxes (*Alopex logopus*) from Kiska Island, Alaska (Byrd *et al.* 1988). Most foxes were killed but at least one fox remained on the island until June 1988. Subsequently, a fox was trapped and Kiska Island probably does not have a viable fox population (Bailey 1993). Residues of 1080 in fox muscle indicated that most foxes consumed more than one bait (Tietjen *et al.* 1988). Non-target mortality was not observed in bald eagles (*Haliaeetus leucocephalus*), or common ravens (*Corvus corax*), but two glaucous-winged gulls (*Larus glaucescens*) were confirmed by 1080 residue analysis to have died after the baiting (Byrd *et al.* 1988).

The potential risk of primary and secondary hazards of 1080 baiting depends upon many factors including the susceptibility of the target and non-target species, concentration in the bait, amount of bait applied, availability of carcasses to a scavenger, and the time of year the bait is applied (McIlroy 1981; Hegdal *et al.* 1986; McIlroy & Gifford 1992). Knowing the feeding habits of the target and non-target species is crucial to developing baiting techniques to minimize exposure to non-target species. This study shows that by reducing bait concentration, 1080 consumption by target species could be reduced to a minimum lethal level to reduce secondary toxicity to scavengers while still maintaining effective control.

ACKNOWLEDGMENTS

This study was conducted by the U. S. Fish and Wildlife Service with funding under Interagency Agreement IAG–14–16–0009–83 between the U. S. Forest Service and the U. S. Fish and Wildlife Service.

REFERENCES

Atzert, S. P. 1971: A review of sodium monofluoroacetate (Compound 1080) – its properties, toxicology, and use in predator and rodent control. U.S. Department of the Interior, Fish and Wildlife Service, Special Scientific Report—Wildlife No. 146. 34 p.

Aulerich, R. J.; Ringer, R. K.; Safronoff, J. 1987: Primary and secondary toxicity of warfarin, sodium monofluoroacetate, and methyl parathion in mink. *Archives of environmental contamination and toxicology 16*: 357–366.

Bailey, E. P. 1993: Introduction of foxes to Alaskan Islands-history, effects on avifauna, and eradication. U.S. Department of the Interior, Fish and Wildlife Service—Resource Publication 193. Washington, D.C. 53 p.

Burns, R. J.; Connolly, G. E.; Okuno, I. 1986: Secondary toxicity of coyotes killed by 1080 single-dose baits. *Proceedings vertebrate pest conference 12*: 324–329.

Burns, R. J.; Tietjen, H. P.; Connolly, G. E. 1991: Secondary hazard of livestock protection collars to skunks and eagles. *Journal of wildlife management 55*: 701–704.

Byrd, G. V.; McClellan, G. T.; Fuller, J. P. 1988: A study to determine the efficacy and environmental hazards of Compound 1080 (sodium fluoroacetate) as a control agent for arctic fox (*Alopex lagopus*) on Kiska Island, Aleutian Islands Unit – Alaska Maritime National Wildlife Refuge. Unpublished report, U.S. Fish and Wildlife Service, Adak, Alaska. 33 p.

Colvin, B. A.; Hegdal, P. L.; Jackson, W. B. 1988: Review of non-target hazards associated with rodenticide use in the USA. *European and mediterranean plant protection bulletin 18*: 301–308.

Finney, D. J. 1971: Probit analysis. 3rd ed. Cambridge Univ. Press. 333 p.

Hegdal, P. L.; Gatz, T. A.; Fite, E. C. 1981: Secondary effects of rodenticides on mammalian predators. *Worldwide furbearer conference proceedings 1*: 1781–1793.

Hegdal, P. L.; Fagerstone, K. A.; Gatz, T. A.; Glahn, J. F.; Matschke, G. H. 1986: Hazards to wildlife associated with 1080 baiting for California ground squirrels. *Wildlife Society bulletin 14*: 11–21.

Hornshaw, T. C.; Ringer, R. K.; Aulerich, R. J. 1986: Toxicity of sodium monofluoroacetate (Compound 1080) to mink and European ferrets. *Environmental toxicology and chemistry 5*: 213–223.

Hudson, R. H.; Tucker, R. K.; Haegele, M. A. 1984: Handbook of toxicity of pesticides to wildlife (2nd. ed.). U.S. Department of the Interior, Fish and Wildlife Service—Resource Publication 153. Washington, D.C. 90 p.

Marsh, R. H.; Schmidt, R. E.; Howard, W. E. 1987: Secondary hazards to coyotes of ground squirrels poisoned with 1080 or strychnine. *Wildlife Society bulletin 15*: 380–385.

McIlroy, J. C. 1981: The sensitivity of Australian animals to 1080 poison. II. Marsupial and eutherian carnivores. *Australian wildlife research 8*: 385–399.

McIlroy, J. C. 1983a. The sensitivity of Australian animals to 1080 poison. V. The sensitivity of feral pigs, *Sus scrofa*, to 1080 and its implications for poisoning campaigns. *Australian wildlife research 10*: 139–148.

McIlroy, J. C. 1983b. The sensitivity of Australian animals to 1080 poison. VI. Bandicoots. *Australian wildlife research 10*: 507–512.

McIlroy, J. C. 1984: The sensitivity of Australian animals to

1080 poison. VII. Native and introduced birds. *Australian wildlife research 11*: 373–385.

McIlroy, J. C.; Gifford, E. J. 1992: Secondary poisoning hazards associated with 1080-treated carrot-baiting campaigns against rabbits, *Oryctolagus cuniculus*. *Wildlife research 19*: 629–641.

Okuno, I.; Meeker, D. L.; Felton, R. R. 1982: Modified gas-liquid chromatographic method for determination of Compound 1080 (sodium fluoroacetate). *Journal of the Association of Official Analytical Chemists* 65: 1102–1105.

Sullivan, J. L.; Smith, F. A.; Garman, R. H. 1979: Effects of fluoroacetate on the testis of the rat. *Journal of reproductive fertility* 56: 201–207.

Thompson, W. R. 1947: Use of moving averages and interpolation to estimate median-effective doses. I. Fundamental formulas, estimation of error, and relation to other methods. *Bacteriological reviews 11*: 115–145.

Tietjen, H.; Deines, F.; Stephensen, W. 1988: Sodium monofluoroacetate (1080): a study of residues in arctic fox muscle tissue. *Bulletin of environmental contamination and toxicology* 40: 707–710.

Weil, C. S. 1952: Tables for convenient calculation of median-effective dose (LD50 or ED50) and instructions in their use. *Biometrics* 8: 249–263.

Winer, B. J. 1971: Statistical principles in experimental design. 2nd Ed. McGraw-Hill, New York. 907 p.

Wildlife Research Center Library
90016960